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ABSTRACT

The purpose of this paper is to assess the differences in university oceanography students' scientific writing. Specifically, the authors examine the argumentation structures of a high scoring paper and a low scoring paper. This study was conducted in an introductory level oceanography course in a large public university. In this course students used an interactive CD-ROM, "Our Dynamic Planet" (Prothero, 1995), which provided them access to geological databases. Students were instructed to use information from this CD-ROM to write the course required scientific technical paper. The authors considered the assessment of writing in two ways. First, they analyzed the differences among and within three populations' assessments of the students' written texts. The three populations had varying degrees of experience and knowledge in geological sciences and are as follows: instructors (n=4), science students (n=9), and non-science students (n=8). Second, the authors applied an argumentation analysis model to the student papers. This allowed them to further identify differences in the argumentation structures of the papers. Based on the analyses, it was found that while all three interview populations were able to recognize differences between the two papers, their reasoning for such differences were rather ambiguous. Applying the argumentation analysis model allowed for further specification of differences in the argumentation structure for the papers. This study draws on these findings to discuss ways of teaching students the construction of argument in scientific writing. (Contains 27 references, 7 figures, and 4 tables.) (Author/ASK)

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Assessment of differences in university oceanography students' scientific writing

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Abstract

The purpose of this paper is to assess the differences in university oceanography students' scientific writing. Specifically, we examine the argumentation structures of a high scoring paper and a low scoring paper. This study was conducted in an introductory level oceanography course in a large public university. In this course students use an interactive CD-ROM, "Our Dynamic Planet" (Prothero, 1995), which provides them access to geological databases. Students are instructed to use information from this CD-ROM to write the course required scientific technical paper. We considered the assessment of writing in two ways. First, we analyzed the differences among and within three populations' assessments of the students' written texts. The three populations had varying degrees of experience and knowledge in geological sciences and are as follows: instructors (n=4), science students (n=9), and non-science students (n=8). Second, we applied our argumentation analysis model to the student papers. This allowed us to further identify differences in the argumentation structures of the papers. Based on our analyses, we found that while all three interview populations were able to recognize differences between the two papers, their reasoning for such differences were rather ambiguous. Applying our argumentation analysis model allowed for further specification of differences in the argumentation structure for the student papers. We draw on these findings to discuss ways of teaching students the construction of argument in scientific writing.

Assessment of differences in university oceanography students' scientific writing

The purpose of this paper is to study the argumentation structure in student scientific writing from a disciplinary point of view. We are interested in providing a means for the writing genre of geological sciences to be readily accessible and available to students. This issue is examined in two ways. First, we consider how populations with varied knowledge and experience in geological sciences identify and describe their overall opinion of the two papers, authors use of evidence, authors use of figures, and conclusions made by the authors uses of evidence in students' scientific writing. Second, we propose an argumentation model to make visible differences among the student papers.

Research on writing in professional communities has identified the importance of social practices and community norms in defining relevant rhetorical features required f or specific writing purposes within disciplinary contexts (Schwegler & Shamoon, 1991). One key feature in scientific writing is a community's assessment and determination of what constitutes evidence in a given historical moment (Bazerman, 1988). The importance of evidence in science and the recognition of the defining role of disciplinary communities has led educational research examining writing to learn issues in science education to bring epistemological issues to the foreground (Keys, 1999; Prain & Hand, 1999).

Our study stems from an ongoing ethnographic study of discipline specific scientific writing in a university oceanography course (Kelly, Chen, Prothero, 2000; Kelly & Takao, 2000). In an earlier report of research from this course, the authors

(Kelly, Chen, Prothero, 2000) discussed how the epistemology of oceanography was constructed, portrayed, and construed through everyday processes of spoken and written discourse. Their analyses of the ways oceanography was framed through discourse processes revealed three issues regarding epistemology and science: (a) Talk about writing in science used situationally specific meanings to define scientific processes (e.g., definitions of what counts as an observation). (b) Classroom discourse processes positioned science as a way of knowing and communicated particular views about science (e.g., contextual, evidential, contingent). (c) Description of scientific writing processes identified ways science differs from other ways of communicating and knowing (Kelly, Chen, Prothero, 2000, p. 711-713). While this previous study focused primarily on how the instructors framed the discipline through instruction on scientific writing, in this paper we investigate the argumentation structure in students scientific writing. In this way, we examine the epistemological issues associated with formulating evidence in writing.

Theoretical Framework

The theoretical framework for this study builds on research of writing to learn science, argumentation in science, and the rhetoric of science more generally. Our review of recent literature in science education indicates a newly burgeoning interest in research on learning to write in science genres. To date, few research studies have focused on discipline-specific scientific writing, specifically pertaining to geological science. Our study aims to contribute to this relatively under-researched field (Bezzi, 1999).

In a review of the research in the field of "writing to learn science," Keys (1999) called for the use of scientific genres in instruction and the examination of classroom activities that encourage "integrated inquiry and writing" (p. 128). Writing of this sort suggests a tie between the shaping of written knowledge and epistemological issues related to the use of evidence. This issue has begun to be investigated by Prain and Hand (1999) who found that students were not able to explain how knowledge claims were established nor how "writing could act as an epistemological tool" (p. 160). The relationship of writing and knowledge production thus remains under-developed.

The second research field informing our work is derived from studies of argumentation. These studies have analyzed students' and teachers' arguments to consider issues of student reasoning, engagement in scientific practices, and development of conceptual and epistemic understandings has begun to get renewed interest in education (Duschl, Ellenbogen, & Erduran, 1999; Jimenez- Aleixandre, Rodriguez, & Duschl, 2000; Kelly, Druker, & Chen, 1998; Kuhn, 1992; Newton, Driver, & Osborne, 1999). Studies have examined evidentiary authority in teacher-student discourse (Russell, 1983; Carlsen, 1997), ways students reason about socio-scientific issues (Patronis, Potari, & Spiliotopoulou, 1999), and the appropriation of scientific discourse in students' small group conversations (Richmond & Striley, 1996). However, few studies have applied argumentation analysis to examine students' use of evidence in writing, a central practice in scientific disciplines (Atkinson, 1999; Bazerman, 1988).

The third part of our theoretical framework draws from studies in the rhetoric of science – the study of how scientists argue (persuade) in the making of knowledge (Harris, 1997, xii). The production of written texts has played a central role in scientific

communities and analysis of the history of the cultural practices associated with the production of such texts has identified how the uses and purposes of written knowledge have changed with changing mores in scientific communities (Atkinson, 1999; Bazerman, 1988; Swales, 1990). This work suggests that assessment of evidence is a cultural practice and can be investigated empirically. Textual analysis of students' writing and the assessment of this writing by populations with varied experience and knowledge in geological sciences therefore represent ways of understanding how evidence is used in science, and how it can be used by students in their own writing – issues we consider in our empirical study. Our two-part study is designed to identify the role of disciplinary-specific knowledge in assessing evidence, and subsequently, to make visible the practices of formulating evidence in geology writing. Both aspects of the study are oriented toward the goal of making explicit to students the disciplinary practices associated with formulating written evidence.

Educational Setting

This study was conducted in an introductory level oceanography course in a large public university and is part of a larger on-going educational ethnography of the course over the past five years (Kelly, Chen, & Prothero, 2000; Kelly & Takao, 2000). We chose to study this course for its emphasis on scientific writing in geological sciences. Geological sciences has been identified as an underresearched field in science education (Bezzi, 1999) and there is a growing interest in the role of writing to promote learning in science (Keys, 1999).

This undergraduate course satisfies a university writing requirement and emphasizes scientific writing. There are 2 one-hour and fifteen minute lectures per week and an additional weekly two hour laboratory section for this course. Students in the oceanography course are provided with the use of an interactive CD-ROM to access geological databases. This CD-ROM, "Our Dynamic Planet" (Prothero, 1995), was created by the course professor. Data modules relating to plate tectonics are available through the still and moving graphics of this CD-ROM, such as earthquake locations and depths, volcanic locations, and the relative age of islands (Fig. 1). More information about the CD-ROM may be found at http://oceanography.geol.ucsb.edu/.

Students use the information provided to them throughout the course via this CD-ROM, course lectures, laboratory sections, course textbook, and course reader to assist them in completing their mid-term scientific writing assignment. This assignment required students to write a technical paper characterizing three geographical areas using relevant geological data and to reconcile their findings with plate tectonic theory. The course reader provided an outline of the format for the technical paper and included descriptions and examples of each section of the paper.

Research Methods

Our study is organized into two parts. First, we considered the differences among and within three populations' assessments of students' scientific writing. This portion of the study sought to identify differences in interpretation of evidence by populations with differing subject matter knowledge. By comparing across the three populations (undergraduate students enrolled in oceanography, undergraduate students not enrolled in oceanography, course instructors), variations in the assessment of evidence could be

made apparent. Second, we applied an argumentation analysis model to evaluate the argumentation structure of students' papers. We specifically focused one paper rated high by the course instructors and one rated low in order to make explicit the differences in uses of evidence. Through this two-part study we are interested in making the writing genre for geology accessible and available to students.

The researchers (Takao and Kelly) and the course professor collaborated for the selection of the two papers used in this study (one rated high, one rated low in terms of overall quality). Although the two papers chosen for use in this study are not necessarily meant to represent every low scoring paper nor every high scoring paper, they were chosen to represent clearly different levels of overall quality. These two papers were coded so the authors' identity and the papers' scores were unknown to the interview participants with the exception of the professor. The high scoring paper was coded with a red sticker and the low scoring paper was coded with a blue sticker. During the interviews the two papers were simply referred to as "the blue paper" and "the red paper."

The three populations in our study had varying degrees of knowledge in geological sciences: subject matter experts (n=4), the course professor and three teaching assistants; science students (n=9), university students taking the introductory oceanography course; and non-science students (n=8), university students who have not taken the introductory oceanography course. These populations were selected because we were interested in learning how the level of discipline specific knowledge would influence the assessment of the quality of arguments in the students' papers. In other words, we wanted to gain an understanding of the implicit knowledge drawn upon by subject matter experts to assess the quality of geological writing – knowledge that may

not be available for the student population. In the first part of our study we attempt to elicit such knowledge.

The participants were individually interviewed and asked to compare one low scoring student paper with one high scoring student paper in terms of participants' overall opinion of the two papers, authors' use of evidence, authors' use of figures, and conclusions made by the authors. These four issues were identified as important factors to consider in scientific writing (Kelly, Chen, & Prothero, 2000). The participants were asked to read both papers and then given a copy of our open-ended interview protocol (Patton, 1990) to know what questions to expect during their interview (Table 1, Interview Protocol). The interviews lasted between 30 minutes to 90 minutes and with the consent of the participants each interview was audio and video taped. Each interview was transcribed word for word. The transcripts of the interview audio and videotapes served as data for our analysis across and within the three populations' assessments of students' scientific writing.

In our initial analysis we open-coded (Emerson, Fretz, & Shaw, 1995) the transcripts and multiple categories emerged from the data. Further in-depth analysis led to synthesis of the multiple categories into three categories of interviewees' positions regarding the four main issues: ambivalent, favorable, and unfavorable. We then reanalyzed the transcripts and focus-coded (Emerson, Fretz, & Shaw, 1995) the data into these categories. We produced a chart demonstrating the participants' assessments of the low scoring and high scoring papers (Figure 2). As we describe in subsequent sections of this paper, analysis of the interviews revealed that the participants' reasoning patterns were rather ambiguous regarding their assessments of the differences among these two

papers. This led us to make explicit the argumentation structures of the two papers, so that such differences could be made explicit to the student writers.

In the second part of our study, we applied an argumentation analysis model (Figure 3) to examine the two papers used in the interviews. The argumentation analysis model used in this study was initially developed in a previous research study within the larger ethnography of this university oceanography course (Kelly & Takao, 2000). The epistemic level categories were based on Latour's (1987) model of scientific writing. Latour's analysis of scientific writing suggested that scientists typically try to move rhetorically from low induction facts (i.e., very specific, grounded claims) to more generalized statements (i.e., theoretical claims) with respect to specific constructs of the relevant disciplinary-specific knowledge. In developing our initial argumentation analysis model (Kelly & Takao, 2000) we considered geological sciences-specific knowledge in relation to the students' argument structures. In this model there were six epistemic levels, from the most specific, grounded claims (shown at the bottom of the model) to progressively more general, theoretical claims (shown at the top of the model). For the purposes of this study, we reviewed our initial model and in effort to make the categories more definitive we revised the epistemic levels into the following: representations of data, identification of topographical features, relational aspects of geological structures, data illustrations of geological theories or models, geological theory or model proposed by the author, description of geological processes and references to definitions, experts, and textbooks. In this study we added a seventh category to our epistemic levels which is labeled as "PC" (Personal Comment) because it

refers to statements in which the author is seemingly "commenting" to the reader. For complete definitions and examples of each epistemic level refer to Table 2.

The process of sorting each proposition into the relative epistemic levels follows from our previous research study (Kelly & Takao, 2000). The assignment for writing the technical paper included dividing the paper into preset sections: abstract, introduction, observations, interpretations, conclusions, and figures (Kelly, Chen, & Prothero, 2000). We analyzed the differences in epistemic levels of propositions comprising the sections labeled "observations" and "interpretations" of the two student papers since that was where much of the inferential work was done. First, we typed the text from the observations and the interpretations sections of the two student papers into computer files. Then we labeled each sentence with a proposition number for future cross-reference. Next, we sorted each proposition into an epistemic level based on the definitions of the epistemic categories. Then we placed the respective proposition number onto a semantic network (Figure 3). The semantic network indicates whether the sentence was from either the students' observations section (circles) or interpretations section (squares). The initial placement of each statement into the respective epistemic levels was completed by analyst 1 (Takao) and checked by analyst 2 (Kelly). We collaboratively reviewed all cases of disagreement until a consensus was reached. We placed the most specific claims on the bottom of the model and began our numerical system from this level. The numerical system we used was designed for referencing purposes in our rhetorical analysis. Although the numbers are in ordinal progression, they do not represent a quantitative measure of generality, nor should they be considered a measure of validity.

To further analyze the argumentation structure we evaluated links among statements across and within epistemic levels. These links reveal the connections (lexical cohesions, see Halliday & Hasan, 1976) among students' propositions and are depicted on the semantic network as lines connecting propositions. Figure 4 represents the links that we recognized among propositions within and across epistemic levels.

We used the following five criteria to define the links: (a) Our first critierion was explicit links among statements across and within epistemic levels. We defined this as sentences using indexical phrases such as "this" or its" in relation to a preceding or following statement. To illustrate this point consider the following propositions, "The first area that is being examined is the Aleutian Island chain in the Northern Pacific Ocean" and "This area is just off the southwestern tip of Alaska (Fig. 1 area 1)" (high paper area 1 propositions 1 & 2, respectively). Proposition 2 uses "this" to explicitly reference the study area noted in proposition 1 and therefore they are linked to one another based on this first criterion. (b) Our second criterion was repetition of the same words or phrases within each area of the high and low scoring papers. We complied a list of words and phrases pertaining to geological content, such as "trench," "magma," "island," "arc," etc., based on the geological terms from the two papers (Table 3). The words and phrases from the list were searched for in the observations and interpretations sections of each area of the two papers by the following process: First, we typed each of the propositions from the observations and interpretations sections of the two students papers into Microsoft Excel files. Next, we used features of the Excel program to search the files for repetition of exact words by typing in the entire word, e.g. "area", or phrase, e.g. "abyssal plane," and doing a "find." In addition to the links list, we searched for the

same words or phrases specific to each area. For example, the low paper area 1 discusses an "abyssal plane" so we searched for that phrase throughout the observations and interpretations sections of that paper. This search was limited to this particular area because areas 2 & 3 of the low paper and areas 1 & 2 of the high paper did not reference an "abyssal plane." In our link table we did not show cases where words from the Links List were in only one proposition for an area since these propositions were not linked to other propositions. (c) Our third criterion was repetition of similar words or phrases regarding geological content. Again we used the Links List and the Excel files containing the students propositions and used the "find" feature of the Excel program. We typed in parts of a word to represent variations of a word, e.g. typed in "quake-" to represent "earthquake," "earthquakes," "quake," "quakes," or to represent various phrases, e.g. "Aleutian-" represented "Aleutians," "Aleutian Island Chain." Next, we manually reviewed each statement for similar words or phrases. For example, based on our analysis we linked the words "seismic" and "earthquake" which are geologically similar in nature (high paper area 2). The following in as example of similar phrases, the phrase "chain of islands" was linked to phrases consisting of "Aleutian-"(high paper area 1) because for this area of study the author interchanges "chain of islands" with "Aleutian Island chain" and "Aleutians." For this category we also included words that had the same root word but had different suffixes, for example "ocean" and "oceanic." We point out that in our search for words in Table 3 that are hyphenated, for some study areas, we removed the hyphen and searched for the whole word. We did this in the areas that did not have variations of the hyphenated word which allowed for a more specific word search because a search for a hyphenated word is more general than a search for the

entire word itself. For instance, for the low paper area 1 we searched for "earthquake" instead of "quake-" whereas for the high paper area 1 we searched for "quake-" because the author interchanged "quake" with "earthquake." (d) Our fourth criterion was superordinate propositions. We linked propositions that consisted of subordinate terms to propositions with superordinate terms. For example, the superordinate terms "these three facts" from proposition 25 (high paper area 1) correlates with the subordinate three facts noted in propositions 19, 23, and 24. (e) Our fifth criterion was propositions that were sorted into more than one epistemic level. On the semantic network a link was used to connect the proposition numbers that are repeated across various epistemic levels. We point out that this repetition of proposition numbers on the semantic network could make the proposition density appear seemingly higher than the actual true number of propositions being represented on the chart. For example, for the high paper number area 1 there are actually 24 propositions, 3 of which are sorted across three epistemic levels and 5 which are sorted across two epistemic levels, giving the appearance that there are 35 propositions. However, a closer look at the chart will show that some of the proposition numbers are actually repeated and should not be mistaken to represent additional propositions. Based on these five criteria, we calculated the amount of links across propositions.

Analyses & Findings

We conducted our analyses process of the two student papers in two phases. First, we analyzed the interview transcripts across and within the three populations' assessments of the high scoring and low scoring papers. Second, we applied our

argumentation analysis model to further illustrate the differences among the high scoring and low scoring paper.

In the first phase of our analysis, we considered the data from the interview transcripts. The interviews focused on four main issues: participants' overall opinion of the two papers, authors use of evidence, authors use of figures, and conclusions made by the authors. Several analyses lead to the synthesis of participants' positions regarding these issues into three categories: ambivalent, favorable, and unfavorable. We defined these categories as follows. Ambivalent referred to participant responses that were neither favorable or unfavorable towards the issue. For example, the following quotes are from the transcripts regarding the participants' overall opinion of the two papers. The first quote pertains to the high scoring paper and the second quote pertains to the low scoring paper and the coded data inside the parentheses reference the speaker, transcript page, and transcript line number, "not a great paper but it's better written" (TAI 3;7;142), "it [low scoring paper] was alright I don't think it got an A in my opinion" (OSI 9-1;1;012). Favorable referred to cases when the participant spoke positively of the issue under discussion. The following examples illustrate the participants favorable positions regarding their overall opinion of first the high scoring paper and second the low scoring paper, "excellent paper its easy to read its concise it doesn't throw in a lot of irrelevant stuff its correct very excellent" (II;20;480), " it was really good I think that you'd get a good grade" (PSI 2;6;062). Unfavorable referred to participant responses that were negative regarding the issue at hand. For example, "it stinks" (PSI 2;4;042) describes this participants overall opinion of the high scoring paper, whereas "there's a definite lack of understanding that's apparent" (II;13-14;312) refers to the overall opinion of this

participant in regards to the low scoring paper. We point out that these categories do not necessarily imply that the participant favors one paper over the other with regards to each particular issue. For example, the participant could speak favorably of both papers in terms if the same issue. The following two quotes serve to illustrate this point and are from the same participant regarding their position of the authors' conclusions for first the high scoring paper and second the low scoring paper: "conclusion well thought out" (OSI 6-1;3;024), and "conclusion really good" (OSI 6-1;5;056).

We created a chart demonstrating the participants' positions in terms of the four main issues for the low scoring and high scoring papers (Figure 2). At this point in our analyses we examined the information in the chart and began to make comparisons between the low scoring and high scoring papers. Based on the chart, we found that more of the interview participants spoke favorably of the high scoring paper than of the low scoring paper in terms of the following issues: participants' overall opinion of the paper (n=14 high paper, n=3 low paper), authors' use of evidence (n=14 high paper, n=3 low paper), and conclusions made by the authors (n=12 high paper, n=6 low paper). In regards to the authors' use of figures, the instructors (n=4) all spoke favorably of this category for the high scoring paper and unfavorably for the low scoring paper. On the other hand, more of both the science students and the non-science students spoke favorably of the use of figures in the low scoring paper (7 science students, 5 non-science students) than that of the high scoring paper (2 science students, 3 non-science students). This analysis revealed that in terms of these four issues, the high scoring paper is regarded by the three populations as favorable in more instances than that of the low

scoring paper. This was not a surprising result, but rather formed a basis to consider the reasons offered for the relative differences in uses of evidence.

Comparison of the participants' positions regarding the four categories indicated that in general the high scoring paper was favored relative to the low scoring paper by the three populations. Although it seems somewhat to be expected and logical that our study would find that a high scoring paper would be preferred rather than a low scoring paper, the reasons for which it was favored were nevertheless ambiguous. Analyses of the transcripts revealed that the participants' were not particularly articulate in their reasoning for their relative positions regarding the four main issues. For example, a science student (OSI 3-1) states "the second one [high scoring paper] is a lot stronger than the first one [low scoring paper]...it's definitely well written." The transcripts following this statement indicated the participant lacked clear reasons for the preference for the high scoring paper as "stronger" and "well written." This was a typical response; participants made general overall assessments of the papers, yet they were not specific in pointing out examples from the papers to support their positions.

We recognize that perhaps this lack in discussion of specific reasons for preferring one writing sample over another was due in part to the interviews themselves (Kvale, 1996; Mishler, 1986; Spradley, 1979). However, even the geology graduate student graders were ambiguous about the differences between the high scoring and low scoring papers. Therefore, to unpack such the differences in uses of evidence across the two papers, we applied our argumentation model to the students' writing.

In the second phase of our analysis, we applied our argumentation analysis model to the high scoring and low scoring papers and noticed several differences among them.

First, in the high scoring paper, theoretical claims (epistemic level V) were supported with data presented across multiple epistemic levels (I, II, II, IV). To illustrate this point we now present the argumentation structure for the high paper Area 1: Aleutian Islands. The author, "Steve," used earthquake, volcanic, and topographical (i.e., trench) evidence to support his theoretical claim that a convergent subducting plate boundary exists at the Aleutian Island chain. These three sub-arguments were constructed with claims across various epistemic levels. For example, consider the earthquake evidence he used for that particular argument. Steve first introduced the subject of earthquakes in proposition 4 which was sorted into epistemic level PC, "The first thing that I looked at is the earthquake activity in the area." " He referenced several data representations (epistemic level I) to provide support for his theoretical claim, such as in proposition 14: "Figures 8 and 9 show the depth of the earthquakes along the profiles that were plotted." He built his argument by identifying topographic features in propositions that were sorted into epistemic level II such as, "There appears to be at least two hundred earthquakes directly along the chain of islands (Fig. 2)" (proposition 5). The next level of generality pertains to relational aspects of geological structures (epistemic level III) and the following proposition (#15) was sorted into that category, "As observed in figure 8, the majority of the quakes are within 50 km of the surface, however there are about 20 recorded earthquakes that extend down the trench to around -252 km." Steve's argument is further supported with proposition 19 which illustrated his theoretical claim with geological data from the study area (epistemic level IV), "The abundance of earthquakes in the area and their locations is the first clue as to what type of tectonic process we are seeing." For this particular argument, Steve also included a proposition which references information from

the course textbook (epistemic level VI), "It is known that at convergent plate boundaries there are deep earthquakes, volcanoes, and a deep trench at the boundary between the two plates (Ross, Oceanography, p. 52)". These propositions (epistemic levels I, II, III, IV, and VI) served as evidence for his theoretical assertions in propositions 26 and 25 claiming the study area is a subduction zone (Figure 5).

Steve continued to use evidence across epistemic levels to support his theoretical claims in the second study area of his paper. Again he used earthquake evidence as noted in proposition 2, "The first step to determining any boundary type is by looking at the earthquake activity in the area" (epistemic level PC). He used several data references in propositions 5 and 18 (epistemic level I) and built his argument by identifying topographic features of the area (epistemic level II) such as in proposition 3, "Along this stretch of the ridge, about 3500 km in length, there are about 100 seismic occurrences (Fig. 3)." Steve referenced data (epistemic level IV) in proposition 18 to further support his theoretical claim (epistemic level V) that the Mid Atlantic Ridge is a plate boundary (propositions 12 and 22).

In comparison, the low scoring paper had multiple general geological theories which were left relatively unsupported by specific reference to and use of geological data throughout the three study areas. We now turn to the argumentation structure of the low paper, specifically the first geographical area identified by the student (South America) to illustrate this point. The author, "Linda[1]," made the theoretical claim (epistemic level V) that "Many factors indicate that the Western Coast of South America is a subduction

[1] The two papers were chosen without the reviewers knowing the students' gender. As it turned out, the strong paper happened to be written by a male student, and the weak paper by a female. However, in a larger, representative there were no gender differences as measured argumentation strength or in student grades (see Kelly & Takao, 2000).

zone" in proposition 14. Linda used earthquake evidence as one of these factors. Unlike the high paper, in which case we could trace Steve's use of earthquake evidence across epistemic levels, in this low paper the evidence exists in only one epistemic level from one proposition, which is proposition 17: "The earthquakes along the trench also indicate a subduction zone." When analyzing this paper we found it difficult to decipher the other "factors" she intended as evidence. Therefore, this particular area illustrated a case in which Linda's theoretical claims were seemingly unsupported (Figure 6). In the case of area 2, again Linda presented earthquake evidence to support her theoretical claim (epistemic level V) that "The Himalayas were formed by a continental/continental plate collision (See Figure 4)" (proposition 7). Earthquake evidence was referenced in propositions 4 and 5 which were sorted across only epistemic levels II and III leaving her theoretical assertions relatively unsupported. For area 3, Linda discussed volcanic activity as evidence for her theoretical assertion (epistemic level V) that "The Hawaiian Island Chain was formed by a hot spot" (proposition 11) in only one proposition (6) (epistemic level II). She did reference other volcanic information in propositions that were sorted into epistemic level V (propositions 1, 3, 7, 10, and 16) and VI (propositions 12, 14, and 15) which essentially do not use data from the study area as evidence to support her theoretical claims . In sum, Linda made a large number of unsupported theoretical assertions.

Second, propositions from the high scoring paper were relatively evenly distributed across the various epistemic levels in comparison with that of the low scoring paper. A majority of the propositions from the low scoring paper were classified into epistemic level V or higher (Area 1: 17 of 28; Area 2: 11 of 17; Area 3: 18 of 24) (Figure

7). The distribution of propositions is related to our first finding discussed above. As previously noted, the high paper used evidence across multiple epistemic levels so that we would see these propositions distributed across our semantic network. On the other hand, the low scoring paper has a more skewed distribution of propositions which relates to our previous finding that supporting evidence was generally absent as there were few lower-inference propositions aligned with particular theoretical assertions. In addition, theoretical assertions of epistemic level V in the high scoring paper were proposed strictly in their "interpretations" section, whereas the low scoring paper had theoretical statements from both "observations" and "interpretations" sections. This may indicate that Linda was unclear about the level of inference permitted for “observations.”

Third, when analyzing the links across propositions (criteria a-d) we noticed that the high paper has a significant amount of more links for each area, respectively, in comparison to the low paper. For the high paper area 1 there are 245 links and for area 2 there are 222 links. However, for the low paper area 1 there are 129 links, area 2 has 48 links, and area 3 has 154 links. We recognize that each area of each paper have a different amount of propositions which could account for some of the variation in amount of links that we see. In terms of the high paper, area 1 has 29 propositions and area 2 has 22 propositions. In regards to the low paper, area 1 has 28 propositions, area 2 has 17 propositions, and area 3 has 24 propositions. Nonetheless, it is interesting to note the difference in the amount of links among the high and low papers and the difference in the density (number of links / number of propositions) of the links for each area (Table 4).

Although it may seem obvious that links between statements are key components to building a strong argument, this point was not articulated during the interviews. For

instance, findings based on the interviews did not indicate that a difference among the two papers was that the theoretical claims of the high paper was linked to supporting evidence, but we do see this from our model. In other words, our model did allow us to draw out some differences among the papers which were not articulated in the interviews, even for geology graduate student graders. Our findings ultimately allowed us to identify key components of the argumentation structures valued by assessors of evidence, even if such structure was not readily recognizable to them as such.

Discussion & Educational Implications

Based on our findings we point to the differences among the high scoring paper and the low scoring paper and suggest components to consider when constructing arguments in scientific writing. Our argumentation analysis model we proposed in this study provides a means to sort out differences in students' scientific writing. This model helped to make explicit distinctions between university students' high scoring and low scoring papers that were not otherwise articulated during the interviews. We recognize that the two papers in our study are unique in their own right, and undoubtedly have idiosyncratic features. Nevertheless, by applying the model to the students' papers we recognized differences among them and made several inferences in terms of writing strong scientific arguments.

The argumentation structure of strong scientific arguments includes theoretical claims that are supported by evidence across various epistemic levels. The distribution of propositions in strong arguments is relatively evenly distributed across the epistemic levels and the propositions should be linked to one another in building cohesive

arguments. These components can serve as a framework for students to use when constructing written scientific arguments. In addition, the assessment of student writing may be made more consistent by making the argumentation structures in scientific writing explicit. Examples of these applications can be found in the Instructor Manual for the CD-ROM "Our Dynamic Planet" (Prothero & Kelly, 2000).

Specific implications can be drawn for instruction in writing in this genre, for both students and teachers. The task of formulating scientific arguments requires abstraction from specific data to make theoretical claims. However, this abstraction process requires intermediate steps, where the level of claim is more than description of data representations, but not as general as the overall theoretical assertion of the main argument. This requires student understanding certain features of scientific writing. First, students may need experience assessing the level of claim in their own and others' writing. Experience assessing the extent of the generality of claims may give students insight into the types and extent of evidence required for a given claim. Second, the facts need to be "stacked" from most descriptive to most general through progressive abstraction (Latour, 1987). Building a cohesive argument requires making connections across the levels of abstraction. Assessing the relationship of different parts of an argument, and how evidence is formulated for each part, may give students better insight into ways of unpacking the presented evidence. This may have significant implications for science-technology-society issues, where there are often ethical implications mixed with scientific information. Finally, for teachers of scientific writing, the use of this argumentation model identified previously invisible features of the writing task.

Considering the ways that claims are made in an explicit manner may give instructors insight into their own tacit knowledge embedded in the writing process.

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Table 1: Interview protocol

Questions:

1) What do you see as the central purposes of the paper? Why do you think so, please explain.

2) Can you identify the main conclusions of the author? Please explain how you arrived at this interpretation.

3) What evidence has the author presented for her/his conclusions? Can you point to specific examples?

4) Can you find examples of appropriate uses of evidence, that is, a case where you feel the conclusions is justified with data through a sound argument?

 4a) How did the author use the Figures or diagrams to support the conclusion of the paper?
 4b) Would you identify one Figure or diagram and discuss how the author uses it in her/his paper?

5) Can you find examples of where the evidence is lacking or insufficient for the conclusions made?

 5a) Find a particular conclusion and try to identify the reasoning behind it.

6) How would you compare the two papers? Which one was better written? Why do you think so?

7) Do you have any questions that you would like me to answer?

Table 2: Definitions and examples of epistemic levels

Revised Epistemic Categories	Epistemic Categories Definitions	Examples
ɔtion of geological processes (not tied to .t is specific to area of study); reference to initions; reference to expert/textbook	General propositions describing geological processes and referencing definitions, subject-matter experts, and textbooks. The knowledge represented may not necessarily refer to data that is specific to the area of study.	"It is known that at convergent plate boundaries there are deep earthquakes, volcanoes, and a deep trench a the boundary between the two plates (Ross, <u>Oceanography</u>, p.52)." Red (high-scoring) paper (Area 1, proposition #22)
ical theoretical claim or model asserted/ sed by author specific to area of study	Propositions in the form of geological theoretical claims or models specific to the area of study.	"Many factors indicate that the Western Coast of South America is a subduction zone." Blue (low-scoring) paper (Area 1, proposition #14)
rs' geological theoretical claim or model ated with data specific to area of study	Data that is specific to the area of study and illustrates the geological theoretical claims or models proposed by the author.	"We can see from figures 5,6, and 7 that the trench does in fact run the length of the island arc, telling us that the plate on the southern side is subducting under the plate on the northern side." Red paper (Area 1, #23)
ational aspects of geological structures specific to area of study	Propositions describing relative geographical relations amongst geological structures specific to the area of study.	"There also appears to be a large trench on the southern side of the island chain, extending the entire length of the island arc, about 3500 km in length" Red paper (Area 1, #6)
graphical features identified specific to area of study	Propositions identifying and describing topographical features of the geological structure specific to the area of study.	"The length of the trench is approximately 5900 kilometers and the width is 125 kilometers." Blue paper (Area 1, #3)
a charts, representations, locations, age of islands specific to area of study	Propositions making explicit reference to data charts, representations, locations, and age of islands. These may also note the area of study.	"The first area that is being examined is the Aleutian Island chain in the Northern Pacific Ocean. This area is just off the southwestern tip of Alaska (Fig. 1, area 1)." Red paper (Area 1, #1-2)
Personal Comment	Propositions which are seemingly "comments" to the reader made by the author	"There are many good features in this area that will lead to the conclusion on what type of boundary occurs here." Red paper (Area 1, #3)

Table 3: Proposition links words and phrases

1. Age
2. Area
3. Boundary
4. Colli-
5. Continent-
6. Converg-
7. Crust
8. Deep-
9. Depth
10. Erosion
11. Hot spot
12. Island arc
13. Island
14. Land
15. Magma
16. Mantle
17. Mountain
18. Ocean-
19. Plate
20. Profile
21. Quake-
22. Ridge
23. Rock
24. Seafloor
25. Sediment
26. Seismic
27. Spreading
28. Subduct-
29. Surface
30. Topograph-
31. Trench
32. Volcan-
33. Weathering

**Plus words/phrases specific to area of study

Ex.	Low Paper Area 1:	Abyssal Plane
		Turbid- current
		South America
	Low Paper Area 2:	Himalayas
	Low Paper Area 3:	Hawaiian Island-
	High paper Area 1:	Aleutian island chain
	High paper Area 2:	Sea floor spreading
		Age of sea floor

Table 4: Density of links per propositions

	# Links	# Propositions	# Links / # Propositions
High Scoring Paper Area 1	245	29	8.45
High Scoring Paper Area 2	222	22	10.09
Low Scoring Paper Area 1	129	28	4.61
Low Scoring Paper Area 2	48	17	2.82
Low Scoring Paper Area 3	154	24	6.42

Figure 1: Map and earthquake depth profile from CD-ROM "Our Dynamic Planet"

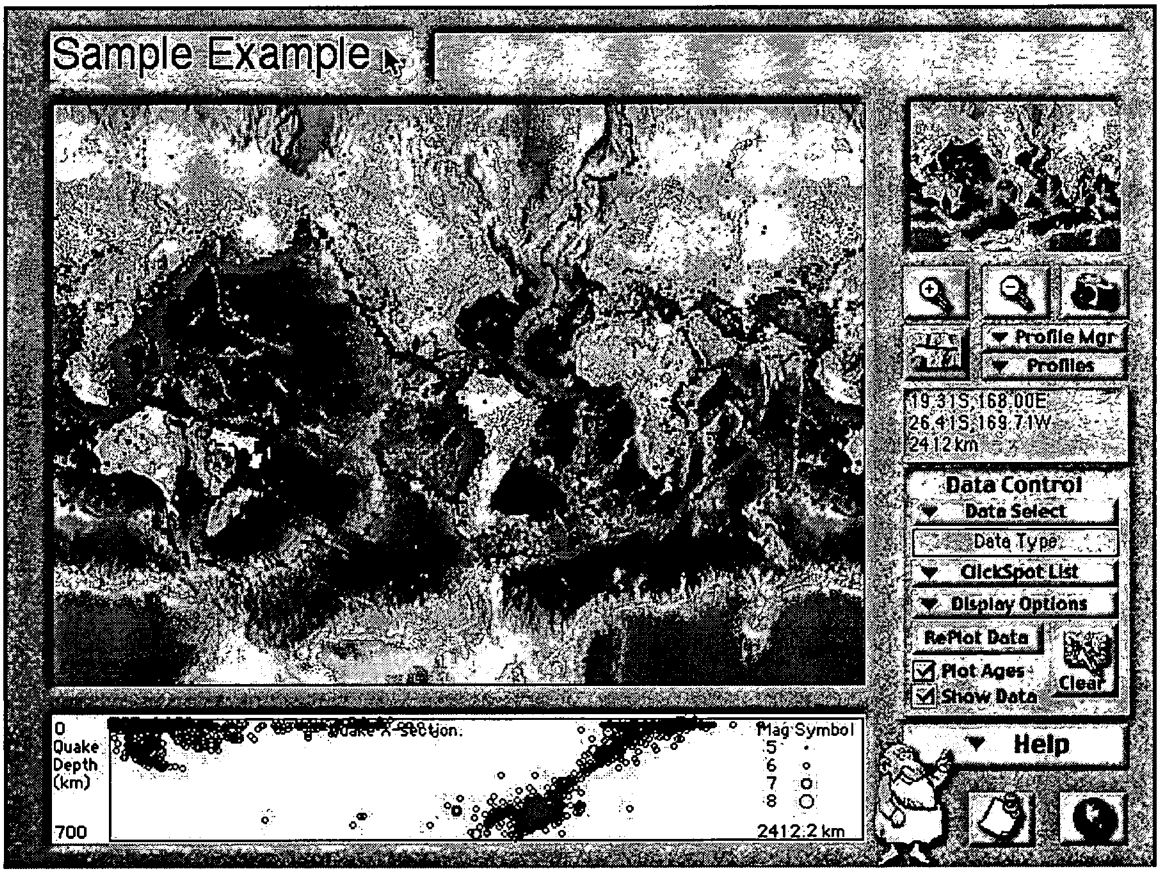

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Figure 2: Summary of the participants' assessments of the low scoring and high scoring papers

KEY: N: number of participants
A: Ambivalent
F: Favorable
UN: Unfavorable
II: Instructor
TA: Teaching Assistant (1,2,or 3)
---: response(s) didn't refer to issue

Issue/	Instructors N=4		Oceanography students N=9		Psychology students N=8	
	Blue paper	Red paper	Blue paper	Red paper	Blue paper	Red paper
Overall Opinion	A (0) F (0) UN (4)	A (2) F (2) UN (0)	A (1) F (2) UN (6)	A (2) F (6) UN (1)	A (1) F (1) UN (6)	A (1) F (6) UN (1)
Use of Evidence	A (0) F (0) UN (4)	A (0) F (2) UN (0)	A (2) F (2) UN (3)	A (1) F (6) UN (0)	A (1) F (1) UN (4)	A (0) F (6) UN (1)
Use of Figures	A (0) F (0) UN (4)	A (0) F (4) UN (0)	A (2) F (7) UN (0)	A (2) F (2) UN (5)	A (2) F (5) UN (1)	A (3) F (3) UN (2)
Conclusions	A (0) F (0) UN (3)	A (0) F (2) UN (0)	A (2) F (4) UN (3)	A (2) F (6) UN (0)	A (0) F (2) UN (4)	A (1) F (4) UN (1)

Figure 3: Model of Epistemic Levels Chart

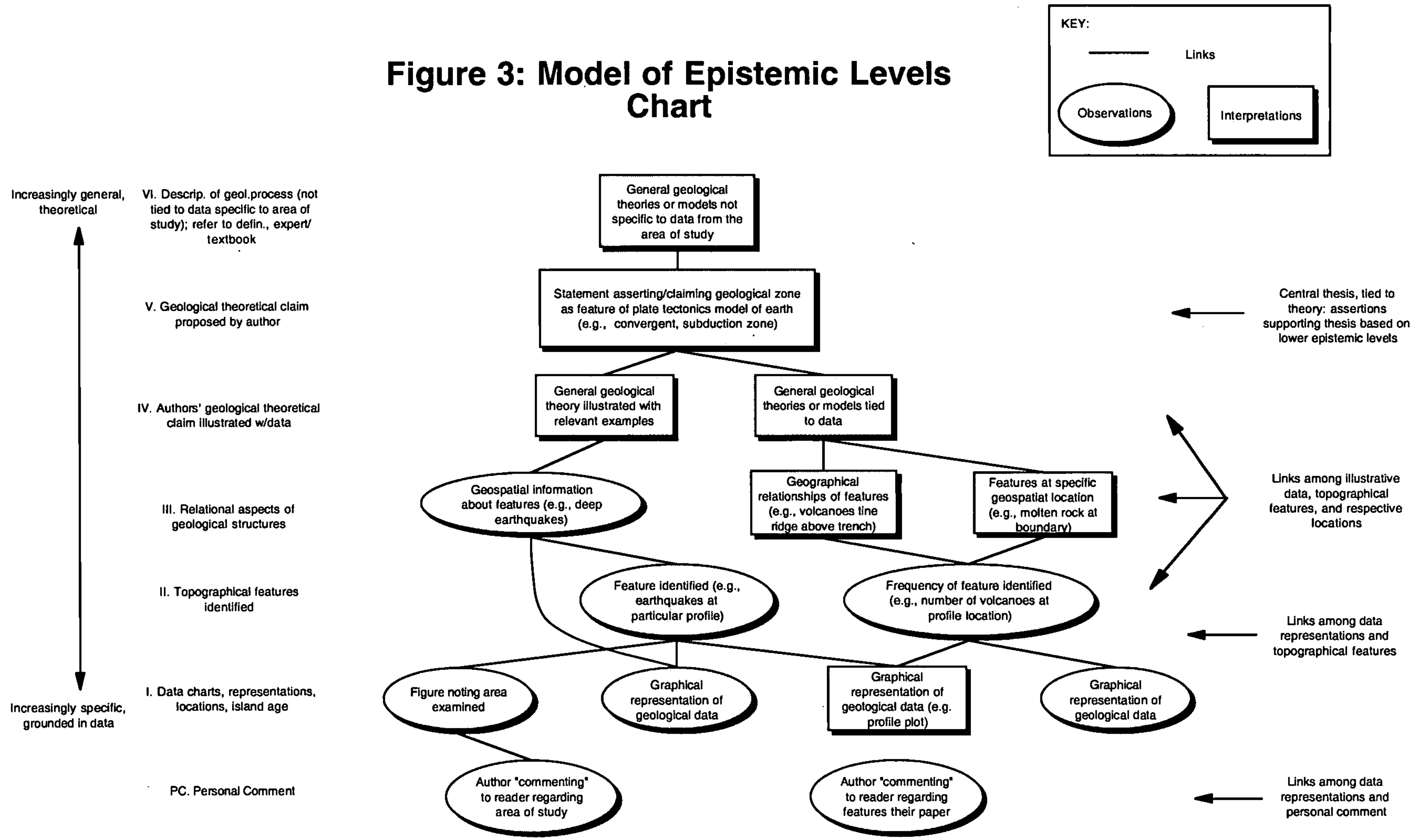

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Figure 4: Sample of links across propositions (1-12) for high scoring paper area 1

Prop #	Proposition	PC	I	II	III	IV	V	VI		Proposition Links	Link Description	Link Criteria
area1:	**Observations: Aleutian Islands**											
1	The first area that is being examined is the Aleutian Island chain in the Northern Pacific Ocean.		•						1	1 2 3	explicit (this)	a
										1 2 3 4 9 12 19	repetition same (area)	b
										1 5 6 17 29	repetition similar(Aleutian Island Chain)	c
										1 5 6 17 23	repetition same (island)	b
2	This area is just off the southwestern tip of Alaska (Fig. 1, area 1).		•						2	1 2 3	explicit (this)	a
										1 2 3 4 9 12 19	repetition same (area)	b
3	There are many features in this area that will lead to the conclusion on what type of boundary occurs here.	•							3	1 2 3	explicit (this)	a
										1 2 3 4 9 12 19	repetition same (area)	b
										3 17 18 20 22 29	repetition same (boundary)	b
4	The first thing that I looked at is the earthquake activity in the area.	•							4	1 2 3 4 9 12 19	repetition same (area)	b
										4 5 13 14 15 19 20 21 22 26	repetition similar (quake-)	c
5	There appears to be at least two hundred earthquakes directly along the chain of islands (Fig. 2).		•	•	•				5	1 5 6 17 29	repetition similar (Aleutian Island Chain)	c

Figure 5: Epistemic Levels Chart Low
Scoring Paper Area 1
"Earthquake Evidence"
(1 link)

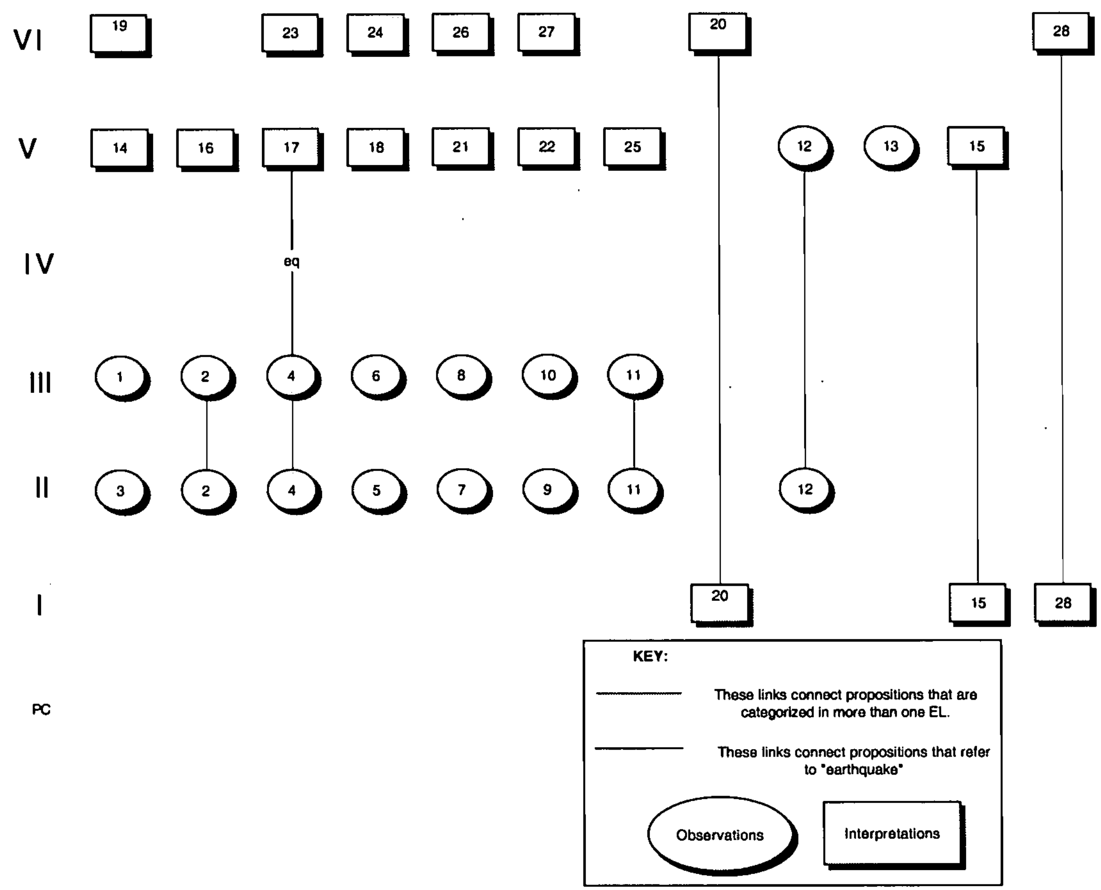

Figure 6: Epistemic Levels Chart High Scoring Paper
Area 1
"Earthquake Evidence"
(45 links)

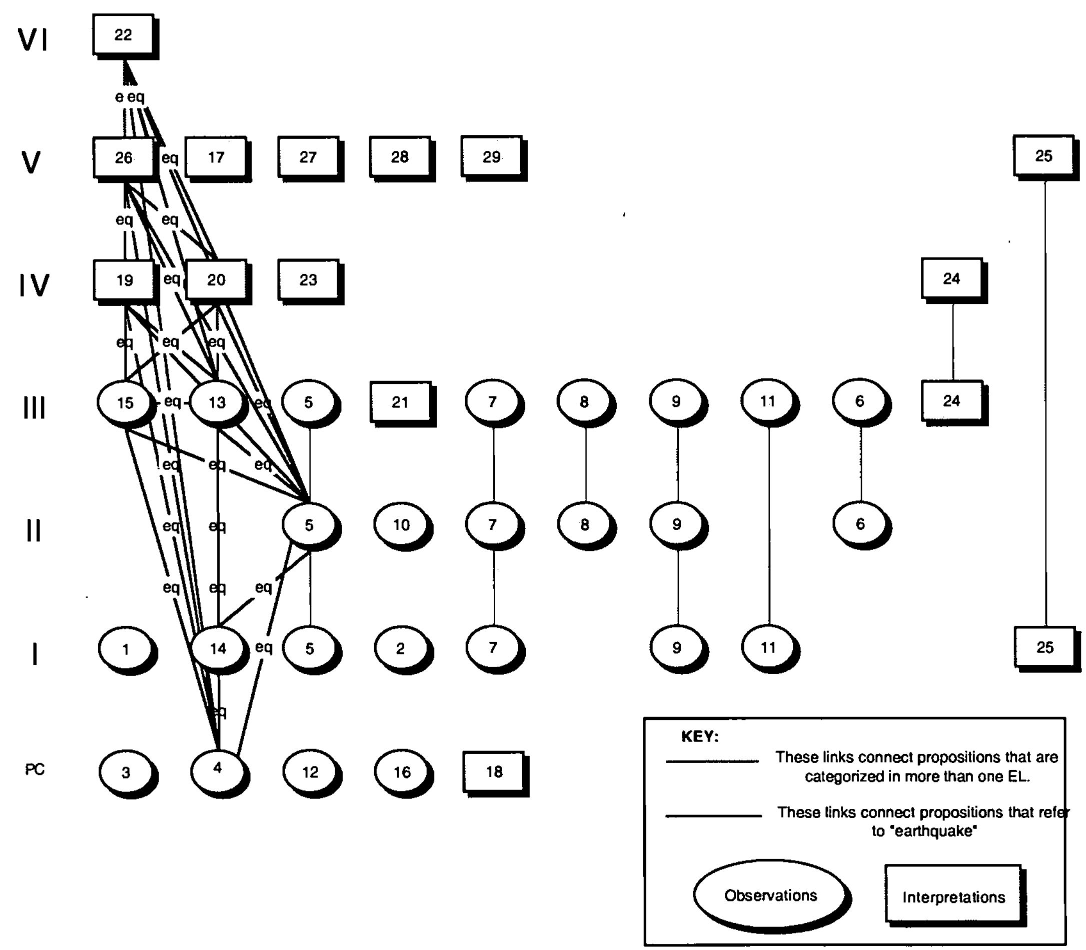

Figure 7: Distribution of propositions for each epistemic level

High Paper
*NOTE: some propositions sorted into more than one epistemic level

Epistemic Level	**Area 1 (29 propositions)**	**Area 2 (22 propositions)**
VI	1	3
V	6	4
IV	4	1
III	10	10
II	6	3
I	8	8

Low Paper
*NOTE: some propositions sorted into more than one epistemic level

Epistemic Level	**Area 1 (28 propositions)**	**Area 2 (17 propositions)**	**Area 3 (24 propositions)**
VI	7	2	5
V	10	9	13
IV	0	0	0
III	7	2	3
II	8	3	4
I	3	1	2

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